

SPACE TRACKING

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NASA

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Vice President of the United States of America
Chairman, National Aeronautics and Space Council

The Honorable Dean Rusk
Secretary of State

Mr. James E. Webb, Administrator
National Aeronautics and Space Administration

Dr. Harry Goett, Director
Goddard Space Flight Center

Commander Walter M. Schirra, Jr.
Astronaut



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PROGRAM

FIFTH ANNIVERSARY

INTERNATIONAL TRACKING OF SPACE VEHICLES

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January 31, 1963



U. S. SPACE - TRACKING

FIFTH ANNIVERSARY

The tracking station network was activated to track Explorer I, launched January 31, 1958. The network included Minitrack stations located primarily in the Western Hemisphere. Since that time, other networks have been added to form a truly world-wide tracking network and data acquisition system for satellites and space probes.

These networks present a unique opportunity for contributions to the pattern of open cooperation and the spread of interest and competence in space research. NASA has 27 overseas facilities in 19 different political areas. About two-thirds of them already operate with the assistance of foreign nationals. The cost of operating several of the NASA network stations is largely borne by the cooperating nations. Each network is specifically designed to fulfill the requirements particular to each of the major programs.

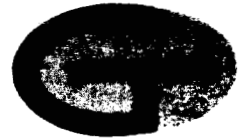
1. The Minitrack network, established during the International Geophysical Year, tracks and gathers data transmitted from unmanned scientific satellites such as Vanguard, Explorer, Orbiting Solar Observatory, etc. There are eight Minitrack

Stations in seven political areas.

2. The Deep Space Instrumentation Facilities (DSIF) are equipped with powerful transmitters and sensitive receivers which can maintain contact with spacecraft traveling to the moon and beyond. There are DSIF in two countries abroad. (2)

3. The Manned Space Flight network, originally built to meet the requirements of Project Mercury, is capable of faster data handling and tracking than Minitrack. This network provides continuous ground contact, monitoring and communications with the capsule, from launch until landing, in order to assure the astronaut's safety. There are eight ground stations in seven political areas abroad. (3)

4. The Smithsonian Astrophysical Observatory, under a NASA grant, operates a world-wide system of Baker-Nunn telescopic cameras. This optical tracking serves as a back-up system for ground radio stations. It provides information on atmospheric densities and is employed in geodesy -- the determination of exact distances on earth. There are Baker-Nunn installations in nine countries abroad. (4)



TRACKING AND DATA ACQUISITION AND REDUCTION

A spacecraft with the finest scientific instruments, launched perfectly into orbit, is worthless unless it can be tracked to determine where it is, and its scientific information retrieved and recorded on the ground. Then the data, recorded on magnetic tape, must be reduced into facts and figures in order that the scientist can analyze the results of his space-borne experiments.

To accomplish this task, the Goddard Space Flight Center serves as the tracking, communications and computing hub of NASA's world-wide Minitrack and Manned Spacecraft Networks.

In addition, the Jet Propulsion Laboratory, Pasadena, California, operates Deep Space Instrumentation Facilities for the tracking and data acquisition of lunar and planetary satellite projects. The Smithsonian Astrophysical Observatory operates 12 optical tracking stations each equipped with a Baker-Nunn telescopic camera.

Thirteen Minitrack stations which serve as "eyes and ears" for un-manned scientific satellites provide precision tracking, command and telemetry data to the Space Operations

Control Center at Goddard.

These stations are constantly being modified to track and acquire data from the more advanced spacecraft which have been developed by NASA and the others that are sure to be developed in the future.

Most of today's small satellites will give way to the large orbiting observatories. This will increase the complexity, range of operation, mission duration and volume of data. Improved ground facilities to handle the new generation of spacecraft are needed. Some already exist; others are in the planning stage.

Existing equipment for the big observatories consists of an 85-foot antenna at Rosman, N. C., and another at Fairbanks, Alaska. In addition, one more is under consideration for Rosman and one for a station in the Far East. These antenna systems, because of their high power and sensitivity will handle information in much greater volume and variety.

For manned space flights, the Goddard Space Flight Center operates a global network of stations for tracking, telemetry, and voice communications on a "real-time" basis. The focal point of this integrated communications system is Goddard's Space Operations Control Center which determines and predicts satellite orbits, and controls a voice network, called SCAMA, linked to stations in the network. Dual high speed computers,

each with a "real-time" channel, make constant flight contingency recommendations, predict flight paths, determine the time to initiate re-entry and predict the impact point of the capsule on a near-instantaneous and continuous basis during the mission. These computers, in the simplest mathematical explanation, can add, for instance, a column of 10-digit numbers $3/4$ of a mile in length every second.

The Manned Spacecraft Tracking system spans three continents and three oceans, interconnected by a global communications network. It utilizes land line, undersea cables and radio circuits, and special communications equipment installed at commercial switching stations in both the Eastern and Western hemispheres.

The project includes buildings, computer programming, communications and electronic equipment, and related support facilities required to direct, monitor, and provide contact with the manned spacecraft.

Altogether, this system involves approximately 177,000 route miles of communications facilities to assure an integrated network with world-wide capability for handling satellite data. It includes 102,000 miles of teletype, 60,000 miles of telephone, and 15,000 miles of high-speed data circuits.

Goddard's site facilities include equipment for acquir-

ing the spacecraft; long range radars for automatic tracking; telemetry equipment for controlling the manned vehicle from the ground if necessary, and voice channels for ground-to-air communications.



MINITRACK - UNMANNED SATELLITE NETWORK

The instrumentation used primarily for unmanned satellite missions is an outgrowth of the Minitrack system originally created as part of Project Vanguard in 1957. This network was used to track Explorer I, first U.S. earth satellite launched on January 31, 1958. (This satellite launched by a modified ABMA-JPL Jupiter-C with U.S. IGY scientific experiment of James A. Van Allen which discovered the radiation belt around the earth.)

Today there are thirteen of these stations located throughout the world. The stations are located at Blossom Point, Maryland; Fort Myers, Florida; Quito, Ecuador; Lima,

Peru; Antofagasta, Chile; Santiago, Chile; Woomera, Australia; Johannesburg, South Africa; Goldstone Lake, California; St. Johns, Newfoundland; East Grand Forks, Minnesota; Fairbanks, Alaska and Winkfield, England.

The number of Minitrack stations and their locations were chosen to insure that at least one station will be within line of sight of a satellite during almost every orbit, regardless of the inclination or the orbital altitude. Each station generates a fan-shaped antenna radiation pattern approximately 11 by 76 degrees. Since, at most, only a few points per orbit are obtained with this system, it is obvious that a very accurate orbit cannot be computed until several orbits have been completed. This tracking method generally satisfies the orbital requirements of unmanned satellites, which remain aloft for long periods of time. This tracking system operates in the frequency band of 136-137 MCS and requires a little acquisition information. The data is automatically sampled and punched, in digital form, suitable for teletype transmission, on paper tape along with time and other appropriate information. It is then transmitted back to the Goddard Space Flight Center for computation of the satellite's position.

Data acquisition from the satellite, or telemetered data, is also transmitted to the ground stations in the 136 to 137 MCS frequency band.

Generally, the telemetry is recorded on magnetic tape, either in predetected or detected form. The magnetic tapes are transported to the central data reduction facility at the Goddard Space Flight Center. This Center also supplies each station with operational control data and the necessary prediction information for spacecraft acquisition.



DEEP SPACE INSTRUMENTATION FACILITY (DSIF)

Deep Space Instrumentation Facilities are used primarily for tracking and data acquisition in support of the NASA lunar and planetary programs. Stations are located at Goldstone, California; Johannesburg, Republic of South Africa; and Woomera, Australia. The Network Control Center is at the Jet Propulsion Laboratory, Pasadena, California.

The Goldstone Tracking Facility is located at a remote site in the Mojave Desert near Barstow, California. The Goldstone facility, named for adjacent Goldstone Dry Lake, was selected as the site for these antennas, because it offers extremely low background noise levels. Due to the sensitivity

of the receiving equipment used, man-made interference from automobile ignition systems, aircraft radios, power lines, and commercial radio and television transmissions must be kept at a minimum.

Three stations within a seven-mile radius comprise the Goldstone complex:

ECHO STATION consists of an 85-foot diameter polar mount antenna, capable of tracking at angular rates of one degree per second. A sensitive phase-locked receiver and a low noise parametric amplifier, a 10 kw maximum power transmitter, and associated data handling and instrumentation systems comprise the basic electronic subsystems. This is the main station and the prime tracking antenna for all transmitting, receiving and data handling capabilities. Supporting laboratories, administrative and engineering offices are located here.

PIONEER STATION consists of an 85-foot diameter polar mount tracking antenna which is identical to that at the Echo Station with the exception that it does not have transmitting capabilities but does have a low noise Maser and Cassegrain feed system. This station is used for both research and development of advanced components or systems, and as a supplementary antenna in a spacecraft tracking mission.

VENUS STATION consists of an 85-foot diameter Azimuth-Elevation (Az-El) antenna mount with Cassegrain type feed.

Advanced receivers, Masers, and parametric amplifiers will be utilized in performing communication research experiments. For extensive testing of special communication systems, an additional 30-foot diameter Az-El mount antenna is available at the station. Advanced development is also proceeding on a 100 kw transmitter which eventually will be used to communicate to the far reaches of the solar system. The central control building services both antennas during a test.

The polar mount antennas are similar to the large radio telescopes used to find and track radio stars. A radio telescope captures most strongly those signals which come from a point directly in front of it. Thus, by continuously pointing the telescope in the direction of the strongest signal, a space vehicle can be tracked in its motion across the sky.

In addition to the Goldstone complex, there is a Mobile Tracking Station for initial spacecraft acquisition at Johannesburg, South Africa, and a transportable Launch Tracking Station at the Atlantic Missile Range, Cape Canaveral, Florida.

The Woomera Deep Space Station has a single 85-foot diameter receiving antenna with tracking, telemetry recording, and Doppler capability. The Johannesburg Station has a 10 kw transmitter identical to that of the Goldstone Echo Station. Thus the installations at Goldstone and Johannesburg have the capability of sending commands to the spacecraft as well as

to track, record telemetry, and obtain Doppler data. The Mobile Tracking Station and the Launch Tracking Station do not have command capability but have low power transmitters to obtain Doppler information.

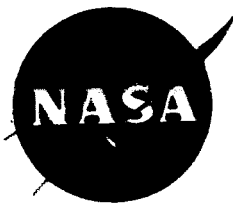
The three permanent installations are located approximately 120 degrees apart around the earth. Their tracking coverage overlaps so as to provide continuous contact with the spacecraft. Throughout the mission each station locks onto the spacecraft, tracks it until the rotation of the earth carries the station to the limits of its horizon, and then passes the spacecraft on to the next station.

Frequencies assigned for use on DSIF missions fall into two general categories: ground-transmitter frequencies and spacecraft-transmitter frequencies. Currently, 890 MCS is used for earth-to-spacecraft transmission and 960 MCS from spacecraft-to-earth. In 1963, the stations will phase into the assigned space communication bands using 2290-2300 MCS for spacecraft-to-earth and 2110-2120 MCS from earth-to-spacecraft.

The present ground telemetering system can accept transmission band-widths of 3.5 KCS and is designed to process FM/PM modulation at 960 MCS. A wide bandwidth detection capability is planned for integration into the DSIF as part of the 2290-2300 MCS receiver.

To provide for the command control of the functions of a space probe, an initial command capability consisting of three audio frequency tones is currently being used. Future command requirements appear to favor a digital technique, and this digital command system is being introduced in the DSIF.

The DSIF Stations, in addition to the gain derivable from their large antennas, also must attribute their ability to communicate across millions of miles of space to their extremely sensitive and stable receivers. These are designed for the purpose of tracking the received RF carrier in phase, and for amplitude and phase-sensitive detection of the sidebands. Doppler data are derived from the local oscillator, telemetry data from either the phase error in the tracking loop or from a separate detection channel, and angle data from separate angle-error detection channels. Currently parametric preamplifiers are being installed which will give extremely high over-all receiving system sensitivities.



WIDEBAND DATA ACQUISITION NET

Many of the satellites to be launched by the National Aeronautics and Space Administration in the future will use very wide bandwidths for transmission of data from the satellite to the ground stations.

Since the receiver and sky noise in the telemetry link is proportional to the bandwidth used for reception, either a very high transmitter power or a very high antenna gain, or both, must be used for wideband telemetry link in order to achieve good signal-to-noise ratios. The transmitter powers are restricted for technical reasons and consequently it is necessary to use very high-gain antennas at the ground stations for receiving the wideband telemetry signals. These satellites will use several of the frequency bands assigned for space use. Therefore, the high-gain antenna must have a capability of operating simultaneously at several frequencies. The antenna that best satisfies the requirements for high gain and multiple frequency operation is a parabolic antenna, 85 feet in diameter.

The first satellite which requires a large data acquisi-

tion facility for wide bandwidth reception will be Project Nimbus, which will be taking television pictures of the earth's cloud cover. Nimbus is one of the satellites that will have a polar orbit. Consequently, the first station for wideband data acquisition has been constructed at Gilmore Creek, 12 miles north of Fairbanks, Alaska. It was completed in May 1962. A contract has been entered into with The University of Alaska for operation of the station. This station will be able to provide coverage for 70 percent of the passes of a satellite in a polar orbit. A contract for construction of a second station to be located near Rosman, North Carolina was entered into in July 1962. This station will pick up an additional 20 percent of the passes of a polar satellite. Thus, these two stations form a network which will provide coverage of 90 percent of the orbits of a satellite with a very high inclination.

The main antenna for the Alaskan station is an 85-foot diameter paraboloid with a focal length of 36 feet. The surface consists of double-curved aluminum sheet panels and is separate from the reflector structure in order that it may be independently adjusted. The reflector is mounted on an X-Y type mount designed specifically for tracking satellites.

The antenna is capable of tracking at rates of 0 to 3° per second, with accelerations up to 5° per second squared. Pointing accuracy is ± 2 min. of arc. The antenna has six

operational modes; will automatically lock-on a satellite signal, or be driven by a teletype drive-tape input. It may be manually operated, slaved to an acquisition antenna, or operated in various search modes for initial acquisition.



THE ROLE OF COMMUNICATIONS IN MANNED SPACE FLIGHTS

Whenever a human life is to be subjected to a calculated risk, American philosophy demands that adequate precautions be taken to assure safety. In the case of manned space flights, we must know where the spaceman is and how he is withstanding his changing environment through all phases of the mission: launch, orbit, re-entry and recovery. From the instant the rocket engines are ignited, the experts in control of the mission must be supplied with exact information concerning the spacecraft's acceleration, speed and direction to enable them to make an intelligent and almost immediate decision as to whether a satisfactory orbit is possible. To do this, high-speed data lines carry radar data from Cape Canaveral and Bermuda to the computers at the Goddard Space Flight Center, and then carry back the computer's answers to the plot boards

at the Manned Space Flight Control Center. The radars at the Cape must talk in a language which is understandable to the computer, and the computer must use a language that the plot boards can understand. Naturally, a digital data code is utilized and the fast-operating, electronically driven plot boards draw their graphs of capsule trajectory parameters only a few thousandths of a second behind the actual capsule position. Not only is the actual position plotted, but the predicted impact point, another rapidly changing item, is continuously displayed. The point of capsule landing on the earth is known at all times, whether or not the booster functions properly or the mission is terminated before orbital insertion occurs. Thus, the Flight Controllers have all the data they need to make their decisions.

At the same time, the Control Center Flight Controllers are in voice contact with the Bermuda Flight Controllers so that a final go-no-go decision can be made by Bermuda if the spacecraft is out of Canaveral's radar range. Bermuda has its own radars, plot boards and high-speed data circuits to assist in making the final decision. Less than a minute is available because if re-entry and impact are to occur before the capsule impact point reaches Africa, the retro-rockets must fire while the capsule is over Bermuda.

Once the capsule is in orbit, the computer at Goddard

establishes the precise orbital track. Radar data coming in from Bermuda, Canary Island, the two Australian Sites, Hawaii and the North American Sites, is analyzed by the computer to determine the capsule's exact position and to predict where it will be 10, 15 or any given number of minutes in the future. The radars talk to the computer in digital language again, but this time, the computer automatically sends out acquisition messages in readable English via teletype lines to each site telling the site crew exactly where to point their tracking antennas and at what time they can expect to locate the capsule.

Meanwhile, the astronaut's physical well-being is checked at each site by voice and telemetry communications from the orbiting vehicle to the site. Because this information is needed at the Control Center and must be handled as rapidly as possible, both voice and teletype circuits are used by the sites to keep the Control Center up-to-date on the status of the mission. Thus, the trained experts at the Manned Space Flight Control Center are in a fully informed status, ready at any moment to do whatever is necessary to insure the Astronaut's safety.

FABRICATION OF THE NETWORK

Since Project Mercury is serving as a proving ground for more sophisticated future space programs, its communications network was designed to permit future modification. For this reason, existing communications facilities were utilized to the fullest extent possible in its fabrication rather than making an attempt to establish a permanent and completely new network. In certain cases, existing facilities could not fill all the requirements and, where gaps became apparent, they were filled by using facilities supplied by the National Aeronautics and Space Administration. Appreciable cost savings resulted from this approach and much better network reliability was achieved since already proved-in circuits and equipment were used. In addition, the built-in versatility of the working equipment and services enabled modifications and additions to be made without the need for extensive design changes.

GENERAL DESCRIPTION OF THE NETWORK

About 177,000 circuit miles are contained in the network. Of this total, about 102,000 miles are teletype, 60,000 miles are telephone, and 15,000 miles are high-speed data circuits. This is all packaged into a 65,000 mile communications route.

A list of the 17 sites involved, together with their abbreviated code designations is given below:

<u>NAME</u>	<u>CODE</u>
Goddard Space Flight Center	GSC
Cape Canaveral	CNV
Manned Space Flight Control Center	MCC
Bermuda	BDA
Rose Knot Ship	RKV
Canary Island	CYI
Kano, Nigeria	KNO
Zanzibar	ZZB
Coastal Sentry Ship	CSQ
Muchea, Australia	MUC
Woomera, Australia	WOM
Canton Island	CTN
Kauai, Hawaii	HAW
Point Arguello, California	CAL
Guaymas, Mexico	GYM
White Sands, New Mexico	WHS
Corpus Christi, Texas	TEX
Eglin, Florida	EGL

NASA Sub-Switching (Relay) Locations

Adelaide, Australia	ADE
Honolulu, Hawaii	HON
London, England	LDN

Messages are carried by land line, submarine cable and radio, connecting a wide variety of radio, teletype and voice equipment. Full time circuits provide all the services needed for message traffic during other than mission periods. Additional circuits are provided during mission periods to guard against delay to mission traffic. Mission periods are defined as times during which the network is used to support actual and/or simulated missions and important tests. The network

uses only two back-up circuits. The one to Bermuda provides a redundant circuit which assures transmission service to this crucial site even if the two primary circuits fail. The back-up circuit for the Indian Ocean Ship via Australia is provided to carry messages in case the primary route fails.

TYPICAL MESSAGE ROUTING DURING MISSIONS

A typical example of how message traffic is carried during a mission is the Canary Island to Goddard circuit configuration. A teletype message originating at Canary during a mission would be able to reach Goddard by any one of the following routes:

1. Full-Time Primary Route - 5218 miles

From Canary by land line to the terminal of Compania Telefono National De Espana, thence via Transradio Espanola radio to London External Telecommunications Executive terminal, thence by transatlantic cable, a joint American Telephone and Telegraph Long Lines and Postmaster General facility to the Radio Corporation of America Communications (RCAC) terminal at 66 Broad Street in New York thence to the AT&T Long Lines terminal at 32 Avenue of the Americas in New York. From there it goes to Washington and Greenbelt, Maryland on AT&T Long Lines facilities terminating at Goddard.

2. Part-Time Route - 5218 miles

A second route using separate circuits on the same general route as the Full Time Primary Route is called up during mission periods to handle the additional traffic created by the mission.



GODDARD SPACE OPERATIONS CONTROL CENTER

The various tracking and telemetry stations throughout the world have been integrated into a coordinated network through a communications system terminating in the Goddard Space Operations Control Center.

The functions of the Operations Control Center are:

1. Control the operation of all tracking, command, and data acquisition, and facilities utilized in support of scientific space vehicles.
2. Coordinate the operation of other ground instrumentation facilities utilized in support of scientific space vehicles, with the exception of certain launch site installations.
3. Ensure that operational activities required in support

of any scientific spacecraft are properly executed according to the operations plan for the spacecraft. In the event of inability to fulfill the operations plan requirements, the control center is responsible for recommending suitable alternative courses of action to the project manager, and making certain that his decision is properly implemented.

4. Provide facilities for monitoring the status of the network and the spacecraft at all times.

5. Ensure that the project manager is kept informed of any departures from nominal in the status of the network or that of the satellite which might effect the conduct of the operation.

6. Schedule network activities to ensure that the requirements imposed are within the operational capability of the network, and to avoid conflicts between individual projects insofar as possible.

7. Provide facilities such that interested officials can follow the critical phases of specific operations and can rapidly obtain information on the status of any satellite during its useful lifetime.

The space control center utilizes the following facilities in the performance of their functions:

Communications. Fourteen telephone toll lines, two local voice loop circuits, two special, external point-to-point cir-

cuits, 12 GSFC extensions, and ten dial intercom positions provide voice contact between external and internal groups performing functions essential to a given operation.

In addition to the routine, in-house routing system for printed messages, the center is tied into the worldwide teletype network via two quasi-real-time TTY data lines and two monitor lines which provide a minimum of delay on circuits of operational importance.

Display. Three large back-lit plexiglass boards convey essentials of mission integrity.

The first of these presents a current Tracking Network assignment and performance schedule in six-hour increments.

The second projects mission milestone and message traffic data pertinent to success probability.

Third and perhaps the most critical of the three: the Iconorama Projection Board. The Iconorama is a computer-driven analog conversion device. It receives digital data from a computing source, converts it into meaningful language that its plotting device will understand, and projects a plot picture of mission time history in terms of launch vehicle and spacecraft velocity.

The Communications Network centering on the Goddard Space Flight Center includes 48 full-period, leased teletype lines serving 85 continental and foreign stations in the Minitrack

and Deep Space Networks, other data acquisition and command stations for scientific satellites, and other agencies in the scientific community engaged in the exploration of space.

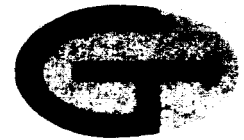
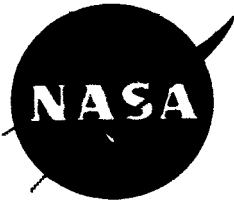
These 48 circuits are terminated in a Western Union 111B switching center which is a system combining torn-tape relay, message switching, and circuit switching capabilities. Circuit combining facilities permit the interconnection of any station in the network in any combination for direct conference or real-time data exchange as needed.

Three TWX, RCA, ACR Western Union commercial TELEX services are available. These circuits are used to carry all types of administrative and logistics information, satellite tracking data, satellite prediction and orbital data, and certain types of telemetry data.

All equipment and circuits in the Operations Room are arranged on a patch panel which permits complete flexibility in interchanging or substitution of equipments and links. One of the page printers is equipped with a keyboard for use in keyboard-to-keyboard coordination of data runs with remote stations in the network. Each of the circuits may be directly connected to any station in the network by leg-combining repeaters under switch control. An off-line 19/14 teletype set is provided for special tape preparation.

In the Control Room, one circuit and two page printers

are provided for coordination and monitor purposes. Any lines in the network may be conferenced in and/or monitored upon request. Outbound traffic from the control room is transmitted to the communications room. Voice communications in the control room are accomplished with standard telephone equipments. Each of 12 operating positions have the capability of utilizing an outside exchange line, local interposition extensions, or a general conference loop. Selected positions have the capability of point-to-point connection for immediate contact to facilities such as the communications room. The Operations Director, the Project Coordinator, and the Network Controller have the capability of selecting any of the lines in the room. Headset transceivers are generally used, leaving the operator's hands free.



GODDARD COMMUNICATIONS CENTER FUNCTIONS

The Communications Center at Goddard is a switching and relay center capable of accepting messages from all sites and automatically relaying them as indicated in Items 1 through 5 below.

1. From any site to the Manned Space Flight Control Center and/or the Goddard Space Flight Center Communications Center.
2. Any site can broadcast to all sites.
3. From radar sites to the Goddard Space Flight Center Computers.
4. From the Control Center, the Goddard Space Flight Center Communications Center and the Goddard Space Flight Center Computers to any site.
5. From the Control Center, the Goddard Space Flight Center Communications Center to all sites simultaneously.

For teletype messages of the types indicated above, the switching or directing is done automatically by having the teletype equipment respond to specific directing codes in the

incoming message address. Thus a message from the Kano Site destined for the Control Center would have the directing code CC in its message address and the automatic switching equipment at Goddard would direct the message upon its arrival to one of the Control Center lines. For Kano to broadcast the message to all sites, a directing code for broadcast messages would be used and the message would be automatically switched and sent to all sites. Should Kano wish to send a message to certain selected sites, not on a broadcast basis, the proper codes would be sent in the address and the message would be manually relayed at the Communications Center to the sites as indicated in the message. There are two very good reasons for arranging the network to perform in this manner:

1. Goddard is able to make a permanent record of all network traffic for post-flight analysis by retaining punched tape records of all messages received.
2. It is much more economical as far as total circuit mileage is concerned to connect all sites to one message center than to inter-connect all sites.

An additional advantage is that Goddard is able to maintain proper network discipline and control since any message can be monitored at any time and any deviation from established practices can be detected and corrected.

With respect to the switching of voice messages, a master switchboard at Goddard called the SCAMA (Switching Conferencing and Monitoring Arrangement) is used. This is a manually operated device which is manned on a round-the-clock basis for the purpose of connecting any two or almost any combination of voice equipped sites together for the conveyance of information. During mission periods, the SCAMA operator generally acts under the control of the Operations Director at the Control Center in making the desired connections. The services available for voice transmission are described in the Voice Network portion of this publication.



VOICE COMMUNICATION NETWORK

A world-wide tracking and ground communication network would not be complete or fully efficient without an adequate voice network. In the case of the Manned Space Flight Network, all of the tracking sites are supplied with voice connections to the switching center at Goddard Space Flight Center.

The Switching Conferencing and Monitoring Arrangement (SCAMA) at the Goddard Space Flight Center is the switching center for the voice network. The telephone lines connecting the SCAMA with each of the stations are leased from domestic U. S. and foreign common carriers.

During mission periods the voice circuits are connected together in a conference configuration which enables the following functions to be performed:

1. The Control Center can be supplied rapidly with real time capsule status information enabling them to deal quickly with any unusual circumstances which may occur.
2. Voice directives from the Control Center can be given to the command sites in case rapid changes in capsule retrofire settings are required for expedited re-entry of the vehicle.
3. All sites having voice capabilities may be fully informed at all times of mission status by monitoring the voice traffic on the conference hook-up.
4. The conversation between the astronaut and the Capsule Communicator at any voice-equipped site can be monitored by all the voice sites on the network.

5. Where an area of overlap occurs between sites in radar or command transmitter coverage, the voice circuits may be used to establish the exact time at which one site ceases transmitting and the next site starts in order to avoid any possible conflict with radar beacon responses or confused command signals.

FACILITIES AND INSTRUMENTATION

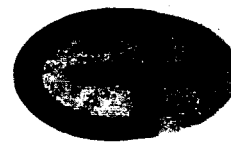
The voice communications circuits use four-wire facilities in which separate two-wire circuits are used for each direction of transmission. This type of circuit is necessary in order to be able to maintain acceptable volume levels with minimum distortion over such an extensive network in which several routes extend half-way around the world. The use of four-wire facilities also simplified the switching problems at Goddard. A wide variety of transmission media are included in the network such as: aerial and underground cable, microwave relay, submarine cable and overseas radio links.

OPERATIONAL USE OF VOICE CONFERENCE HOOKUP DURING MISSIONS

The conference hookup used during missions is arranged by the SCAMA operator at the request of the Operations Director at the Control Center. All the sites having voice capabilities are then connected into one loop. At each site, the Goddard line is connected to the M&O Supervisor's and to the Flight Controller Consoles positions. Although all voice

sites can monitor all communications on the voice network, the SCAMA operator controls the talking access capabilities so that only the site designed by the Control Center can talk into the loop. Usually, this talk capability is given to Bermuda just prior to and immediately after liftoff and is then given, in succession, to the site which has the capsule in view. Thus, the Flight Controllers at the site which is in contact with the capsule can talk directly to the Flight Controllers at the Control Center and, if transmission conditions permit, the conversation between the astronaut and the Capsule Communicator at the capsule-in-view site may be monitored by the whole voice network.

The locations of some radar and command sites are such that an overlap area exists for radar and command transmitter coverage. If two sites send commands simultaneously, or if radar beacon interrogations are sent simultaneously in these overlap areas, the capsule instrumentation could be seriously disrupted. Voice communications are used between any two such sites during a mission to avoid any possible conflict in beacon responses or command signals. By this means, the termination of command and radar beacon triggering transmissions at one site is timed to be only a few seconds before transmission at the next site starts. To arrange for this capability, the SCAMA operator connects the two stations together at the proper time by means of cord circuits on the switchboard.



REAL TIME COMPUTING SYSTEM FOR MANNED SPACE FLIGHT

As part of the Manned Space Flight program, it was necessary to build a ground instrumentation system to provide all the functions for ground control and monitoring of the flight from liftoff to landing. The heart of this tracking network is a real time computing system to provide real time control of the manned mission. This concept involves the real time gathering of data, processing that information, and transmitting and displaying the computed output quantities, without human intervention.

Two principal types of precision tracking radars are being used to automatically track the capsule, the AN/FPS-16 C Band and the VERLORT S Band radar.

One IBM 7090 and one 7094 Computer, operating in parallel, have been installed at Goddard Space Flight Center to drive digital displays and plot boards at the Control Center which supply the necessary information to control the mission. The control link between data sources and data processing in the overall project computation is the IBM Data Communications Channel (DCC) a routing device which makes real time opera-

tion possible. The computers located at the Goddard Computing Center are each connected by a DCC to radar sites and sources comprising the real time tracking and instrumentation system. During a mission all information transmitted to the computers is automatically stacked up in computer core storage by the DCC as it is received. All outputs are transmitted back through the DCC to the required destinations. The DCC thus permits the computer to transmit and receive data automatically while simultaneously proceeding with the real time computing.

A manned space flight mission is usually considered in terms of various stages which are defined as follows:

1. Prelaunch - extends for a period of ten days prior to a mission to liftoff during which time tests, equipment checks and simulations are performed to assure the tracking and computing system are at the acceptable level of readiness for the mission.
2. Launch - extends from liftoff until the flight passes into either abort or orbit mode. The computer recommends a GO or NO-GO after sustainer engine cutoff which marks the end of the launch phase.
3. Abort - an early termination of the launch phase

which extends to the time of escape tower firing or retrofire.

4. Orbit - begins when a GO decision is made and the orbit phase is selected by Control Center personnel. It extends to retrofire.
5. Re-entry - extends from retrofire to capsule landing.

The radar data is transmitted from the radar sites to Goddard via teletype (TTY) lines which are cable, hard wire, radio links, or microwave links. The communication equipment routes the data TTY messages directly to the Data Communication Channel and directly to the block in memory of the computer where it is to be stored awaiting processing. This is performed automatically without human intervention.

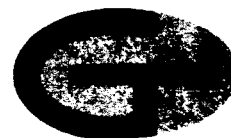
MONITOR SYSTEM

The control system which directs the sequence of computer operations in real time is the monitor. Very simply stated, the Monitor Control Program controls and coordinates the acceptance of input data which arrives on an asynchronous schedule, performs the proper computation on the input information and provides the required output quantities at the specified time intervals.

SIMULATION

For exercise and practice purposes, missions may be sim-

ulated. All necessary data are stored on magnetic tape and may be played from Canaveral in real time to the Goddard computers which simulate the powered flight phase of the mission. Recorded radar data on punched paper tape for each radar site is played into the Goddard computer on scenario over the teletype lines for a particular simulated mission. All displays at the Control Center are activated during simulation and all acquisition data are sent to the sites. This permits full network participation in simulated drills prior to a mission and preparation for future missions.



SMITHSONIAN ASTROPHYSICAL OBSERVATORY TRACKING STATIONS

As a further method of obtaining the position of an earth satellite, the Smithsonian Astrophysical Observatory operates, under a grant from NASA, 12 optical tracking stations. The 12 Baker-Nunn photographic tracking stations are located in Argentina; Australia; Curacao, Netherlands West Indies; Florida; Hawaii; India; Iran; Japan; New Mexico; Peru; South Africa; and Spain. Each station has a standard complement of six ob-

servers. The network is supported by a technical and administrative staff in Cambridge, Massachusetts.

Each station is equipped with a Baker-Nunn camera specially designed for the photographic tracking of artificial earth satellites. The instrument is a three-axis Super-Schmidt f/1 camera, with a focal length of 50 cm, and a field of view $5^{\circ} \times 30^{\circ}$. The camera can track along any great circle at a controllable rate and can photograph satellites to the thirteenth magnitude. The focal field is spherical; a 56-mm film stretched on a focal spherical surface serves for the emulsion support. At the scale of 406 seconds of arc per mm of film, the camera is capable of providing directions with an accuracy of 2 seconds of arc.

Using the predictions that the Cambridge staff specially determines and cables to each station, the observers set the camera so that it will follow the satellite at the correct velocity. This is necessary because many of the satellites are extremely faint and cannot be photographed with a fixed camera.

To date, no satellite orbiting the earth has exceeded the range capability of the Baker-Nunn camera. Vanguard I, the six-inch "grapefruit" satellite, was photographed at distances up to 3000 miles.

At present, the Baker-Nunn cameras satisfactorily photo-

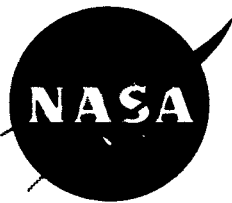
graph more than 2000 satellite passages each month, an output that is the result of constant improvement in station efficiency. On the average, of each 100 passages predicted, about 35 are observed, 40 are lost because of weather, and the remainder are not observed for miscellaneous technical reasons.

By projecting the film on star charts, the observer makes a field measurement from each photographed arc, and promptly cables the result to Cambridge. These field-reduced positions are accurate to within about two minutes of arc and one-tenth second of time; this is sufficient for generating routine predictions and for some scientific work. The films are then airmailed to the Photoreduction Division in Cambridge.

Even though it exceeds the level for which the network was originally conceived, the present output of the Baker-Nunn stations reflects the observational requirements of the satellite tracking program, rather than the actual capacity of the stations. With changes in organization and technique, it should be possible to record a total of approximately 4000 satellite transits each month--more than are necessary to keep continuous watch on all satellites that are now observable by optical means only. The system is capable of contributing to other investigations, such as tumbling studies, cooperative radio-optical observations of flare stars, continuous watch on comets, rocket-launch photography, and asteroid counts.

An attempt has been made to photograph the Lagrangian clouds reported by K. Kordylewski.

The present 12 stations offer an excellent tool for geodetic work, although their importance in this area would be enhanced if observations were available from a few more stations in order to provide better geographical distribution, particularly in higher latitudes. For three-dimensional geodetic triangulation, special mechanical and electronic equipment has been installed to permit simultaneous observations from two or more stations.



HISTORICAL BACKGROUND

Manned Space Flight

The first NASA manned space program, Project Mercury, was organized on October 7, 1958, to:

- a. Place a manned space capsule in orbital flight around the earth;
- b. Investigate man's reactions to and capabilities in this environment; and
- c. Recover the capsule and pilot safely.

For Project Mercury, Goddard designed and operated a global ring of stations which provided vital tracking, telemetry, and ground voice communication on a "real-time" basis. The focal point of this integrated communications system was Goddard's Space Control Center. It determined and predicted satellite orbits, reduced scientific and bio-medical data, and commanded a voice network (SCAMA) which linked ten stations in the Manned Space Flight Network. Dual ultra-high speed 7090 IBM computers, each with a "real-time" channel, made constant flight contingency recommendations, computed the pre-directed flight path and impact points of the capsule, and the velocity vectors on a near-instantaneous, continuous basis during these missions.

During these flights, information flowed into the Goddard Space Computing Center from tracking and ground instrumentation points around the globe at the rate, in some cases, of more than 1,000 bits per second. Upon almost instantaneous analysis, the information was relayed to Mercury Control at Cape Canaveral.

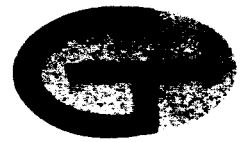
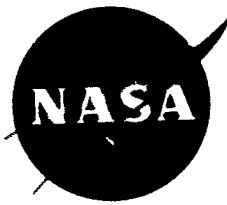
The Mercury Network, because of the man factor, demanded more than any other tracking system. Mercury missions required instantaneous communication. Tracking and telemetered data had to be collected, processed, and acted upon in as near "real-time" as possible. The position of the vehicle had to be known continuously from the moment of liftoff.

After injection of the Mercury spacecraft into orbit, orbital elements were computed and prediction of "look" information passed to the next tracking site so the station could acquire the spacecraft.

During late 1961, an industrial team headed by the Western Electric Company turned over this \$60 million global network to the National Aeronautics and Space Administration.

Other team members were Bell Telephone Laboratories, Inc.; the Bendix Corporation; Burns and Roe, Inc.; and International Business Machines Corporation. At the same time, the Lincoln Laboratories of the Massachusetts Institute of Technology also advised and assisted on special technical problems related to the network.

The concluding contract involved extensive negotiations with Federal agencies, private industry, and representatives of many foreign countries in the establishment of tracking and ground instrumentation.



HISTORICAL BACKGROUND

Minitrack Net

Historically, the first functional network to be constructed for satellite tracking was the "Minitrack" network. This network grew directly out of arrangements originally made by the United States with agencies abroad as part of the program for the International Geophysical Year. Among the overseas stations tied in with the satellite tracking network were Antigua, British West Indies; Quito, Ecuador; Lima, Peru; Antofagasta and Santiago, Chile; Woomera, Australia; and Esselen Park, Republic of South Africa. These countries, in a program originally established in 1957 by the U. S. Naval Research Laboratory in cooperation with other agencies here and abroad, all helped to create the "Minitrack" telemetry system.

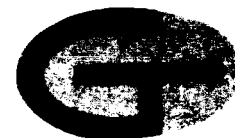
The basic responsibilities of the Minitrack Network included: Tracking, Orbit Computation, Data Acquisition (Environmental and Scientific Telemetry), and Data Reduction.

The Minitrack Net, has been used to track all NASA satellites containing a suitable beacon since the program

began in 1957 and 1958.

A large percentage of the original stations were located along the 75th meridian to intercept satellite orbits with inclinations of less than 45° . New Stations have been located in higher latitudes to cope with higher orbital inclinations. Furthermore, it is planned to supplement ten of the stations with additional antennas aligned specifically for polar orbit.

Since the establishment of the network, certain improvements have been made to the original station equipment to provide tracking capability by optical and Doppler means. While the original tracking equipment operated on or near 108 MC (the frequency assigned for IGY activities), additional equipment has been provided tuneable over the 136-137 MC region. Although basically the same, it incorporates certain features which further increase its capability.



HISTORICAL BACKGROUND

Deep Space Instrumentation Network

The Jet Propulsion Laboratory located in the foothills of the Sierra Madre mountains in Pasadena, California, was assigned, while under contract to the U. S. Army in 1958, the responsibility of launching a series of spacecraft to explore the moon environment. For this purpose a large 85-foot parabolic antenna was permanently installed at Goldstone, California, in a natural bowl in the mountains about 150 miles northeast of Pasadena, and a mobile station was constructed and used in western Puerto Rico. These stations successfully accomplished their objective of tracking space probes Pioneers III and IV. The equipment used in the stations was based on the use of phase locked receivers which had been developed at JPL in 1955 for the Microlock System.

Shortly after these flights, the Jet Propulsion Laboratory, operated by the California Institute of Technology, was transferred to the jurisdiction of the National Aeronautics and Space Administration (NASA). Under NASA, JPL has been given the responsibility of unmanned exploration of deep space at lunar distances and beyond. To accomplish this

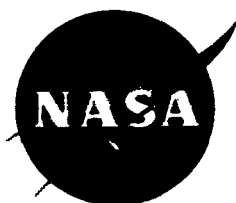
objective, JPL has planned and implemented a series of lunar exploration programs under the names of Ranger, Surveyor and Prospector, and a series of planetary programs under the names of Mariner and Voyager.

In order to continuously track, receive telemetry data and command these spacecraft, arrangements were made in 1959 to construct tracking stations in Australia and in South Africa to supplement the one in Goldstone, California. 85-foot antennas similar to the one at Goldstone were installed at these stations.

In 1960, JPL and the Bell Telephone Laboratories participated in the Project Echo space communication experiment. For this purpose, a second 85-foot antenna was installed at the Goldstone station to transmit and receive communications signals by means of the Echo balloon to the Bell Telephone Laboratories station in New Jersey. Since then, this antenna has been moved to a new site, also at Goldstone, and a second antenna for operational use with deep space spacecraft has been installed in its place. Plans are presently underway for supplementary 85-foot antennas in two new tracking stations near the same longitudes as the South Africa and Australia Stations.

The equipment and the type of antennas used in the Deep Space Instrumentation Facility were particularly designed

for communication with deep space probes. Operations in deep space required precision angular measurements, very low system noise, very efficient telemetry systems and extremely sensitive receivers. The DSIF was particularly well adapted for continuous high reliability communications with spacecraft at distances of approximately 10,000 miles above the earth and beyond. Although the DSIF was designed for use with deep space probes, it has been used occasionally for communications with near earth satellites and sounding rockets.



MAJOR SPACE SCIENCE EXPERIMENTS

<u>PAYLOAD</u>	<u>LAUNCH</u>	<u>SIGNIFICANCE</u>
<u>Astronomy</u>		
Aerobee 25	Nov. 17, 1955	Detected ultraviolet signals from star other than the sun.
Aerobee 31	Mar. 28, 1957	Discovered nebulosities; measured deficiency in stellar ultraviolet emissions.
Aerobee 4:11	Nov. 22, 1961	Provided ultraviolet spectra of 15 preselected stars.
Explorer 11	Apr. 27, 1961	Made first gamma ray spectral measurements.

Cosmic Dust

Explorers 1,
3, 8, and 13

Counted micrometeoroid impacts and measured velocities at impact.

Vanguard 3

Ionosphere

Explorer 8 Nov. 3, 1960

First direct evidence of helium band around the earth; first satellite to measure electron temperature; determined that ionospheric electron temperature varies by time of day.

Ariel Apr. 26, 1962

Found electron temperatures to be greater at the higher latitudes.

P-21 probe Oct. 19, 1961

Verified existence of helium ions.

P-21A probe Mar. 29, 1962

Same as P-21.

Scout TV-2 Oct. 4, 1960

Same as P-21.

Energetic Particles

Explorer 1 Jan. 31, 1958

Discovered Van Allen Radiation Belt.

Explorer 3 Mar. 26, 1958

Verified Van Allen Belt existence.

Explorer 4 Jul. 26, 1958

Found that inner belt zone consists mainly of penetrating (high-energy) protons.

Explorer 6 Aug. 7, 1959

Detected electrical ring current circling outer belt zone.

<u>PAYLOAD</u>	<u>LAUNCH</u>	<u>SIGNIFICANCE</u>
<u>Energetic Particles (cont.)</u>		
Explorer 7	Oct. 13, 1959	Monitored major solar storm simultaneously with Pioneer 5 probe (see below); detected low-energy electrons in outer zone.
Explorer 12	Aug. 15, 1961	Upset Explorer 7 data by finding that the outer zone consists mainly of low-energy protons.
Injun	Jun. 29, 1961	Discovered and monitored high intensity radiation belt formed by July 9, 1962, U.S. nuclear test detonation.
Pioneer 1	Oct. 11, 1958	Found that the outer Van Allen Belt limit varies with solar wind.
Pioneer 3	Dec. 6, 1958	Discovered what was thought to be a second distinct radiation zone.
Pioneer 4	Mar. 3, 1959	Confirmed Pioneer 3 and Explorer 7 data.
Pioneer 5	Mar. 11, 1960	Registered Forbush decrease (decrease in cosmic ray intensity) after solar flare; measured ring currents found by Explorer 6; measured magnetic field and penetrating protons in deep space.
<u>Magnetic Fields</u>		
Pioneer 1	Oct. 11, 1958	Found disturbed transition between earth's magnetic field and interplanetary space at 53,000-mile altitude.

PAYLOAD

LAUNCH

SIGNIFICANCE

Magnetic Fields (cont.)

Explorer 10 Mar. 25, 1961

Discovered draping effect of the earth's magnetic field on the dark side; crossed magnetosphere at 86,000-mile altitude.

Explorer 12 Aug. 15, 1961

Found that magnetic field on the sunlit side "breathes," averaging an altitude of 40,000 miles.

PAYLOAD

LAUNCH

SIGNIFICANCE

Cosmic Radiation

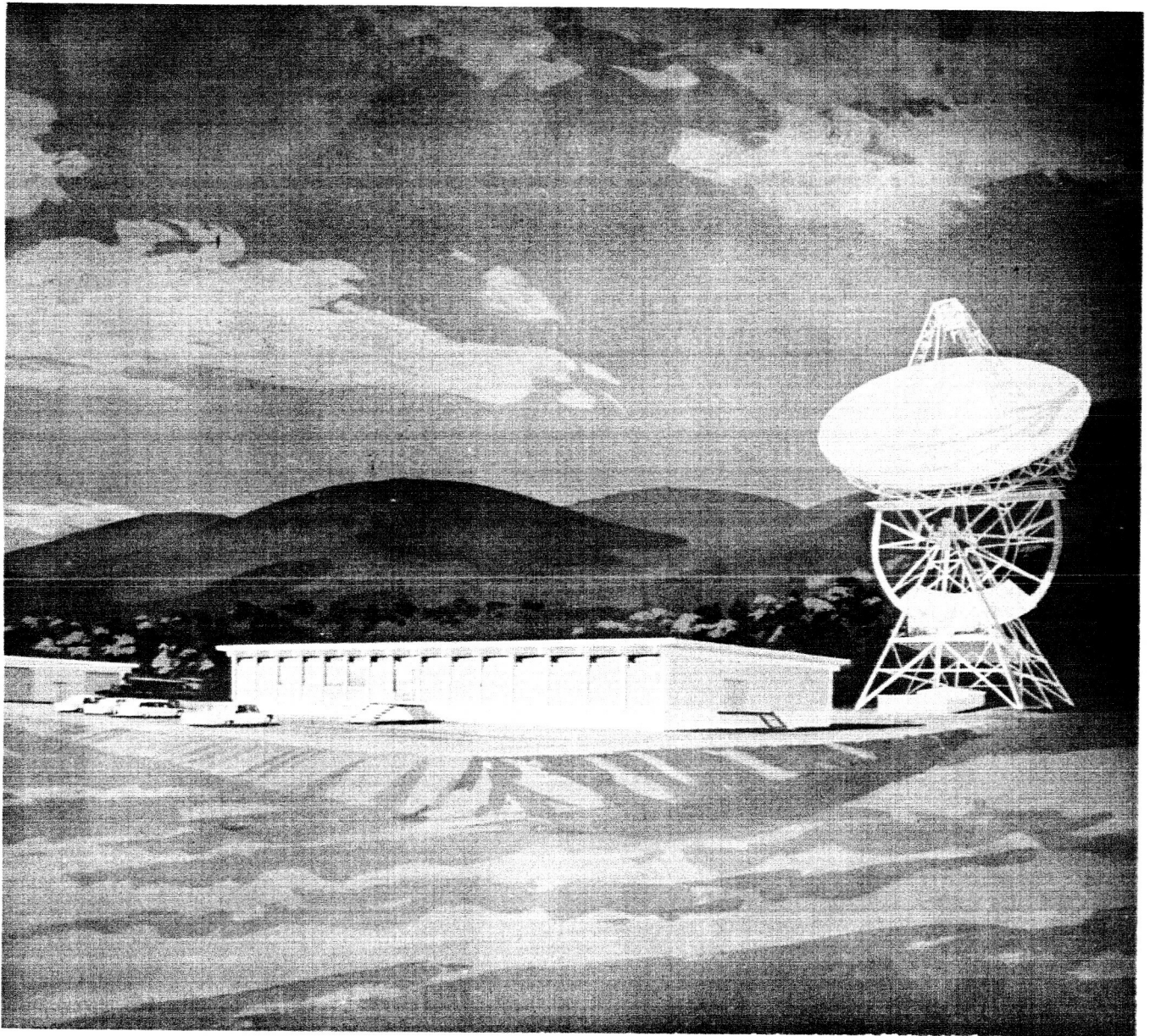
Nerv

Determined that nuclei ratios differ in rays from the sun and rays from stars outside the galaxy.

Solar Radiation

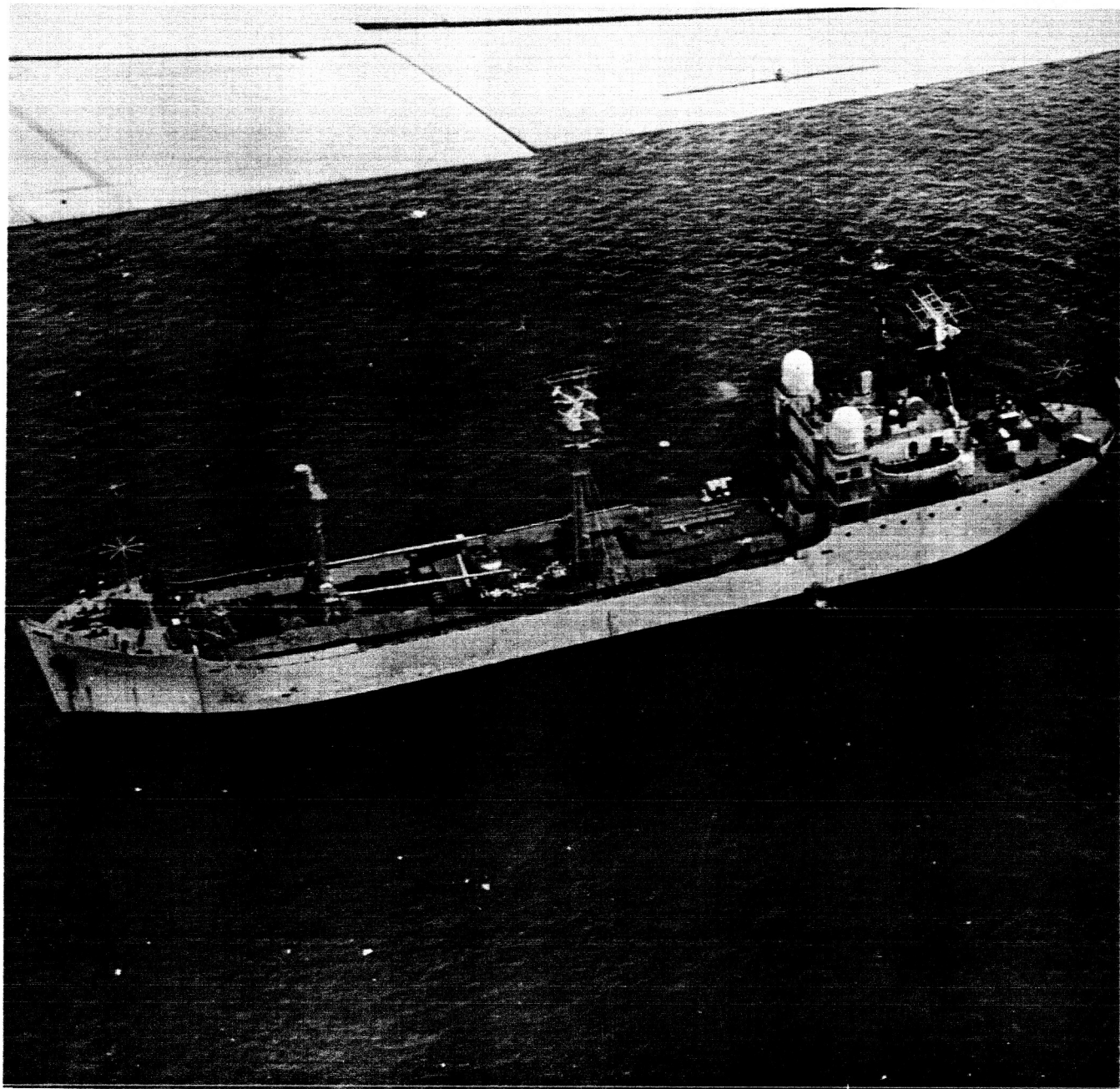
Orbiting Solar Mar. 7, 1962
Observatory

Confirmed rocket data that solar radiation is emitted from bright spots on the sun, which constitute only 3% of the solar surface.



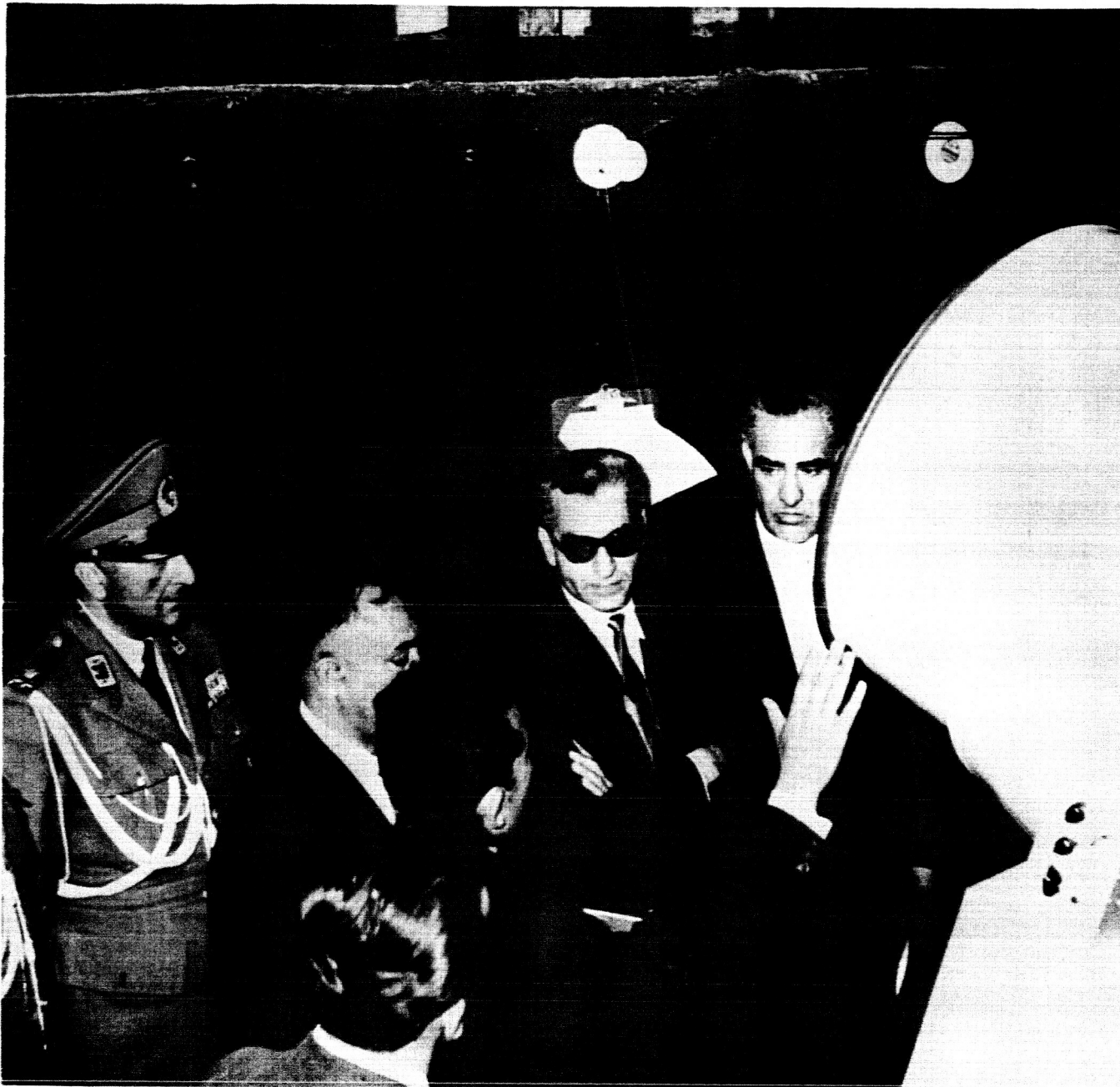
ROSMAN DATA ACQUISITION FACILITY

The 85' antenna shown here weighs 300 tons and stands 12 stories high (120'). It will be capable of receiving satellite signals from 3 different frequencies simultaneously. When coupled to the electronic data system, the antenna will lock onto the satellite signal and follow it across the sky automatically.



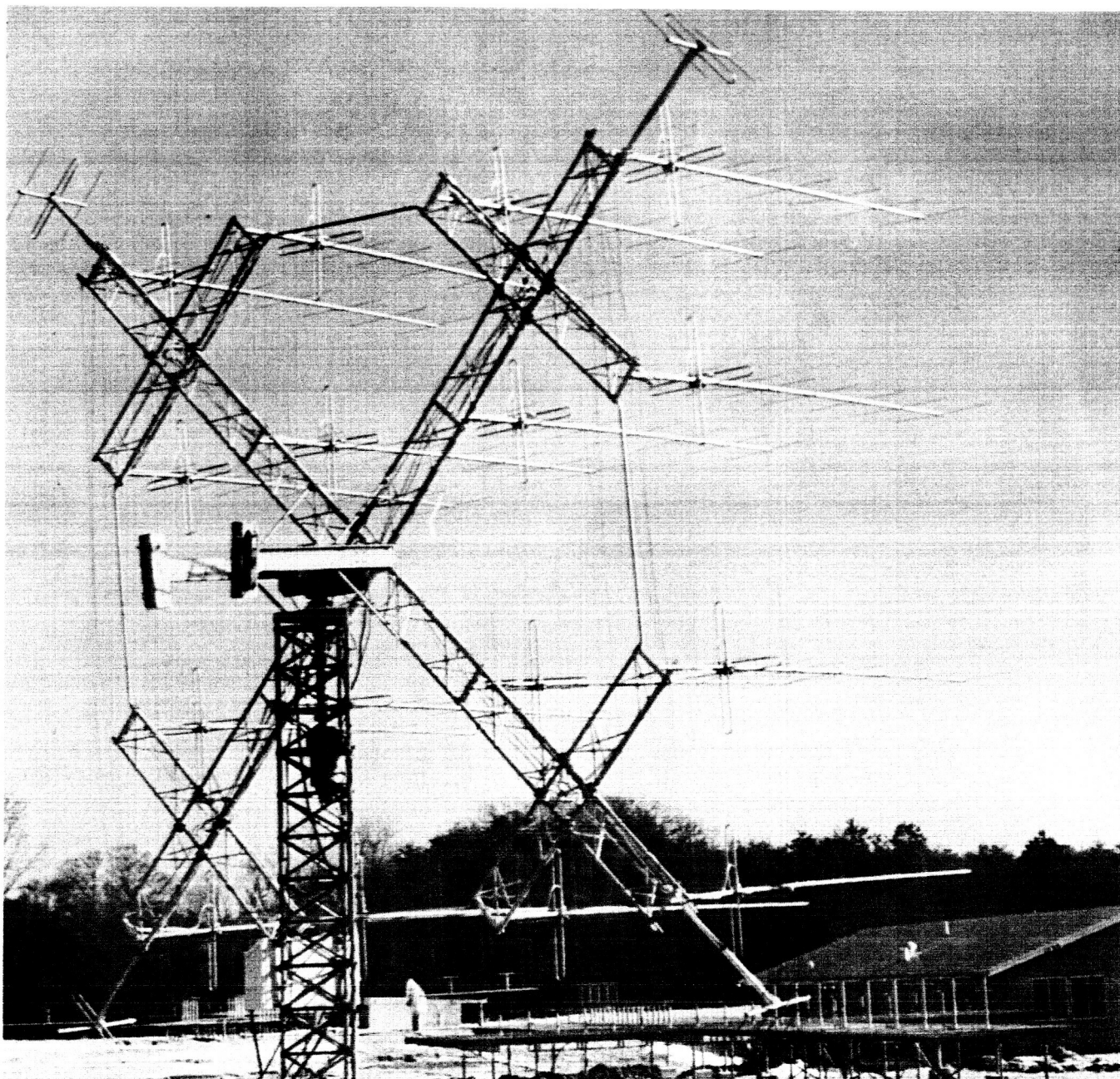
TRACKING SHIP ROSE KNOT

This ship functions as a mobile telemetry station in support of manned spaceflight missions. It has both reception and "command" capabilities.



BAKER-NUNN CAMERA

Operation of the camera at the station in Shiraz, Iran, is explained to the Shah of Iran and party, 4/26/59. Baker-Nunn cameras are operated by the Smithsonian Astrophysical Observatory under NASA grant to optically track and photograph spacecraft.



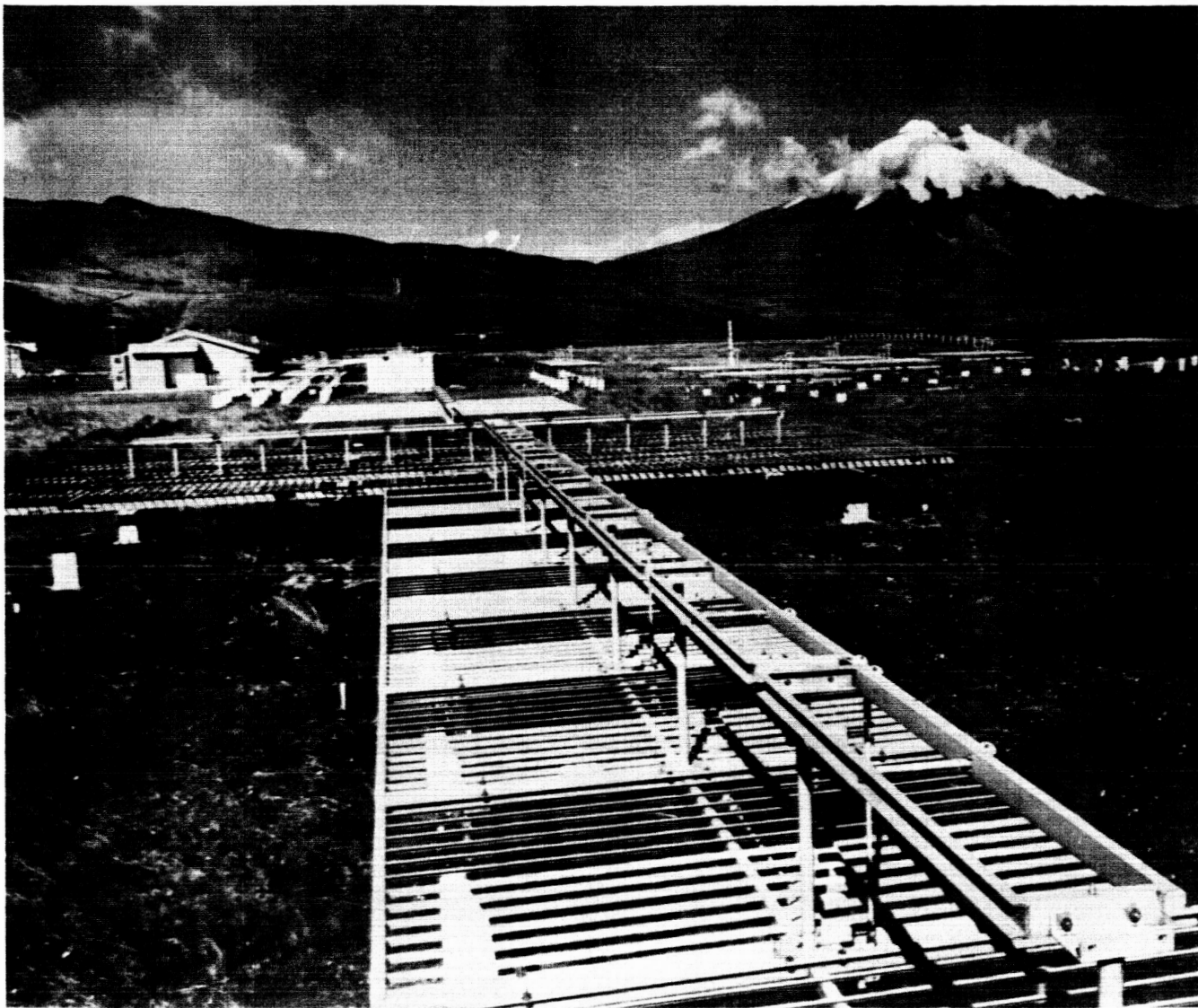
MINITRACK

External view of the Blossom Point, Maryland, Tracking Station showing from the left: an experimental 16 element Yagi antenna; Minitrack antennas (next to the building); and the Operations Building.



MERCURY TRACKING STATION, GUAYMAS, MEXICO

Quad-helix telemetry antenna and mobile power supply.



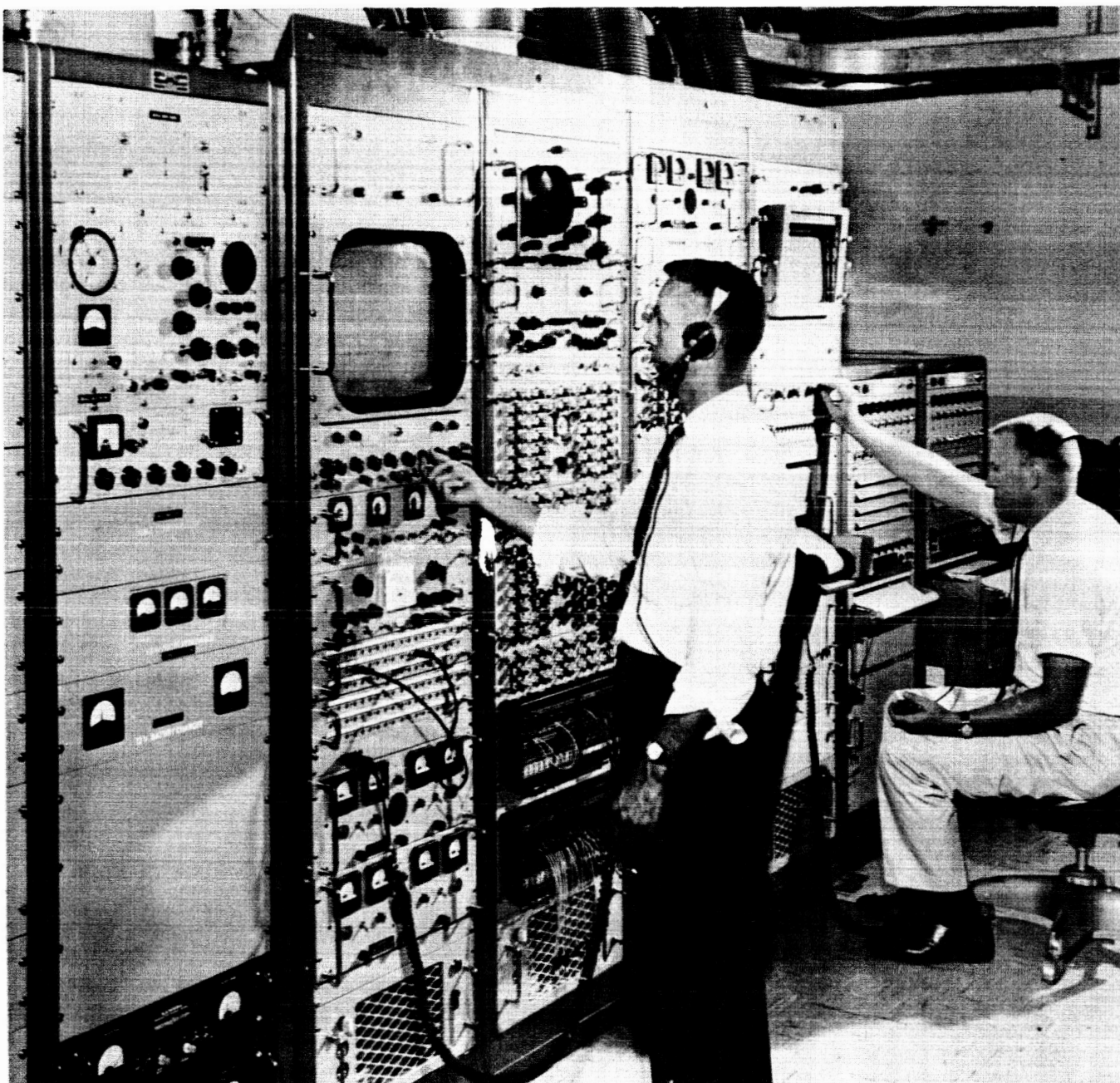
MINITRACK STATION, QUITO, ECUADOR

Base line antenna used to receive telemetry signals of orbiting spacecraft.



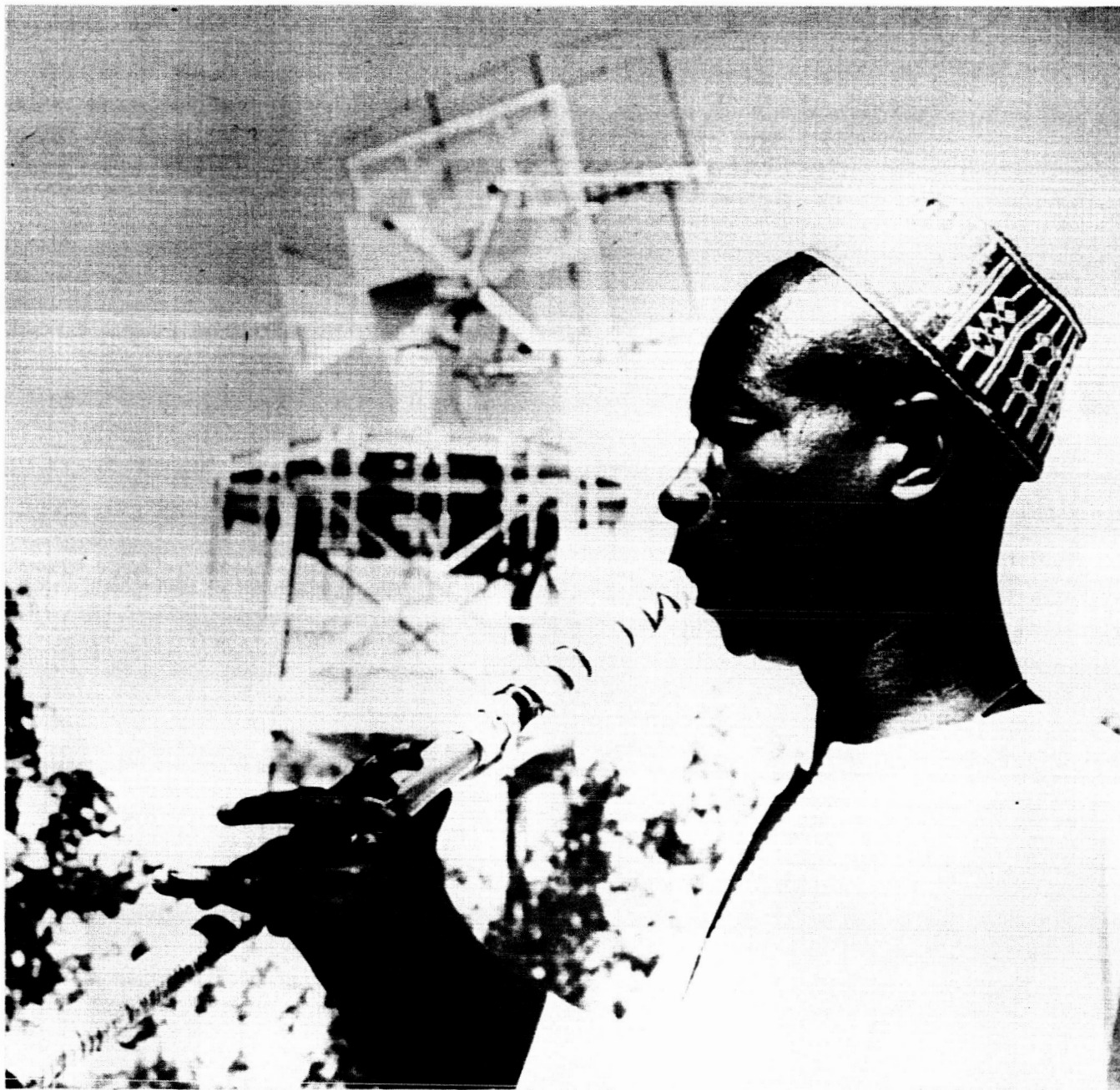
MINITRACK, WINKFIELD, ENGLAND

Calibration Camera



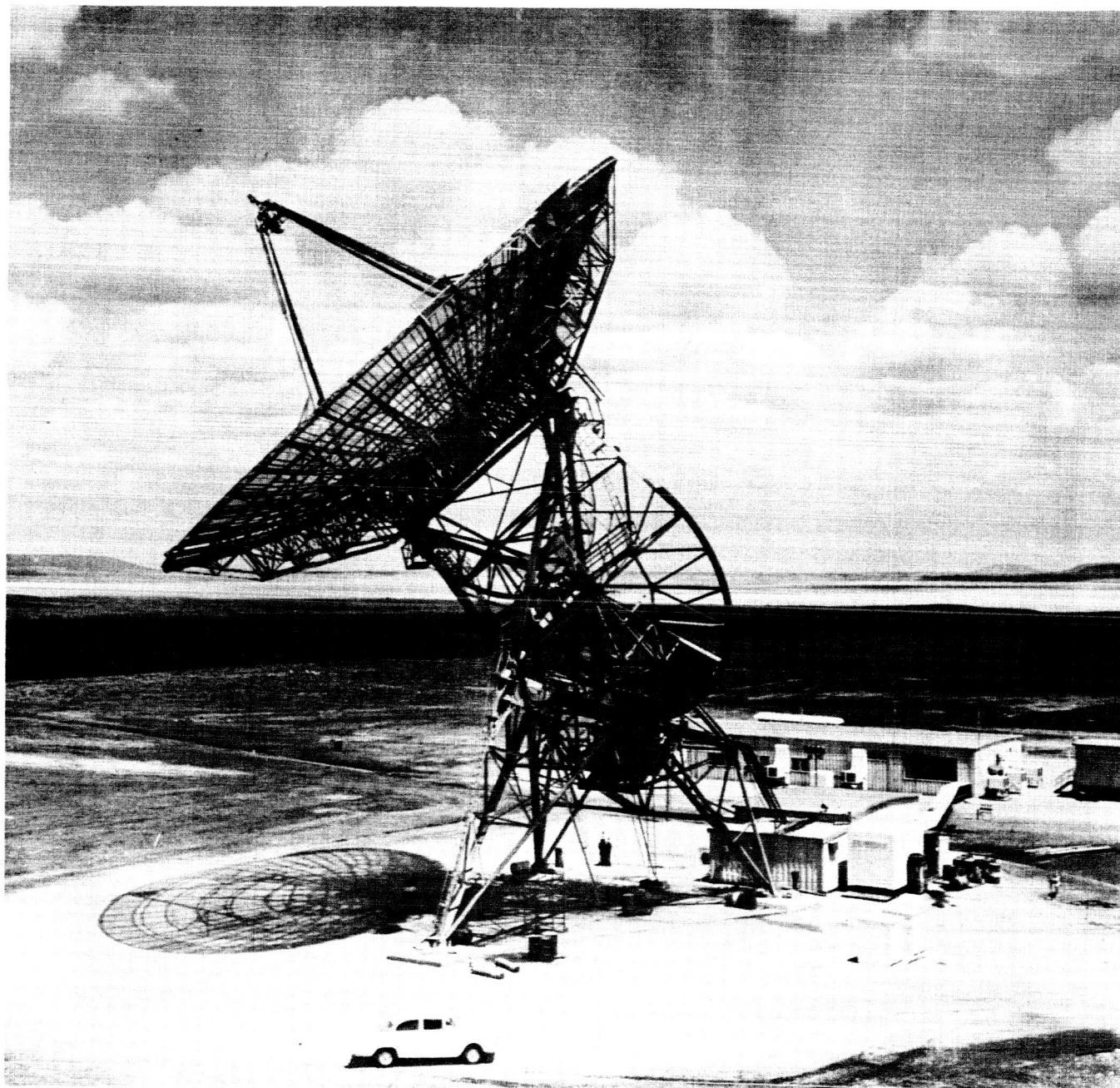
MERCURY TRACKING STATION, WALLOPS ISLAND, VIRGINIA

Telemetry receiving equipment.



MERCURY TRACKING STATION, KANO, NIGERIA

Nigerian tribesman playing native Hausa Flute. Many Nigerian nationals are employed at the Kano tracking station.



DEEP SPACE INSTRUMENTATION FACILITY (DSIF)
WOOMERA, AUSTRALIA

DSIF's are used primarily for tracking and data acquisition in support of the NASA lunar and planetary programs.



DEEP SPACE INSTRUMENTATION FACILITY (DSIF)
GOLDSTONE, CALIFORNIA

DSIF's are used primarily for tracking and data acquisition in support of the NASA lunar and planetary programs.